International Journal of Technology 13(3) 458-472 (2022)
Received November 2021 / Revised December 2021 / Accepted February 2022

International Journal of Technology

http://ijtech.eng.ui.ac.id

Wind Energy Potential in Urban Area: Case Study Prishtina

Gazmend Krasniqi[1], Cvete Dimitrieska[2], Shpetim Lajqi[1*]

[1]University of Prishtina "HASAN PRISHTINA", Faculty of Mechanical Engineering, 10 000 Prishtina, Republic of Kosovo
[2]St. Kliment Ohridski" University, Faculty of Technical Sciences – Bitola, 7 000 Bitola, Republic of North Macedonia

Abstract. Urban wind Energy is one of the new renewable ways of producing electricity, which researchers have not studied very much. From earlier studies, it is impossible to state if it is or is not recommended to install wind turbines in Urban Areas. Further inverstigation are required to have a more accurate answer, including wind potential, suitability and possibility of installation. On the rooftop of the Technical Faculties Laboratory of the University of Prishtina "HASAN PRISHTINA", a Horizontal Axis Wind Turbine and a Vertical Axis Wind Turbine have been installed. Both turbines are with the same capacity of 300 watts. A small meteorological station is installed among wind turbines to provide meteorological data. Results from installing these devices are presented in this research, where the turbines' power production potential is presented. The energy situation in Kosovo is presented, well as the pollution caused from the old fashion power plants. Research also includes the comparision between theoretical and real power production from each turbine separately. The wind data and power production results for both turbines are presented for two years, 2019 and 2020. The more suitable turbine is chosen by comparing the results, after which its main characteristics are shown at the end of the study.

Keywords: Pollution; Power curve; Power production; Urban wind energy; Wind turbines

1. Introduction

Currently, Kosovo produces more than 95% of the power requirements from two coal-based power plants, Kosova A and Kosova B (Rizvanolli, 2019). Units A3, A4, and A5, of Kosovo are still working, while units A1 and A2 are not operating. Three working units of Kosova A produce around 610 MW of energy with a total annual production of 1500 GWh/year.

Kosova B consists of two units: Unit B1 and B2. Both units have an installed capacity of 339 MW each (KEC, 2021). Unit B1 of Kosova B was established and began working in 1983 while Unit B2 began working 1984. The total annual production of Kosova B Power Plant is around 3750 GWh/year (KEC, 2021). Old technology used and the years of work have depreciated the power plant and have made them the biggest pollutants to the environment in the area of Kosovo. The pollution of the environment from these Power Plants includes pollution with dust, SOx, NOx, and other pollutants (Spanca, 2020).

*Corresponding author's email: shpetim.lajqi@uni-pr.edu, Tel.: +383 44 259 771
doi: 10.14716/ijtech.v13i3.5323

The replacement of fossil fuel power plants with renewable energy sources is one of the ways of covering energy needs without harming the environment. According to studies done and renewable power plants that operate in Kosovo, there are possibilities to use different renewable sources in different regions. Kosovo’s Energy Regulatory Office (ERO) is established as an independent body and has the duty to regulate activities in the energy sector. According to ERO, there is a number of Power Plants that produce electricity using different Renewable Sources (ERO, 2020). Wind Energy produces the highest amount of electricity, followed by Hydro Power Plants and Photovoltaic systems (ERO, 2020).

A meteorological station and two wind turbines have been installed on the rooftop of the Technical Faculties Laboratory of the University of Prishtina "HASAN PRISHTINA" for the purposes of this study. While wind turbines produce electricity for the laboratory needs, the meteorological station provides wind data needed for the paper analysis purposes. All the results achieved from wind turbines and meteorological stations are presented in either table form or graphical form.

Because of the obstacles around the spot where devices are installed, wind velocity doesn't show very satisfying results, and neither does the power production. Results show that Horizontal Axis wind turbine (HAWT) gives better performance than a vertical Axis wind turbine (VAWT) for the chosen spot and the circumstances where devices are installed. HAWT power curve and power coefficient are presented graphically in the end of the paper, fulfilling the requests set at the beginning of this research.

Besides the Introduction, the paper is separated into six sections. Section 2 presents Kosovo's energy and environment situation, section 3 presents the literature review, section 4 shows the calculations of the wind turbines power production, section 5 presents the results gained from research and section 6 gives the conclusion and discussion of the results.

1.1. Literature review

A considerable number of studies have been conducted in the field of Urban wind technology. First, in 1998, the European Community implemented a project called Wind Energy for the Built Environment (WEB), which analyses the possibility of installing small wind turbines in urban areas (Campbell et al., 2001). This project also developed a model of wind turbine technology for application in urban areas, which was called Urban Wind Energy Conversion Systems (UWECS) (Stankovic et al., 2009). Urban wind energy technology, the feasibility of building-mounted/integrated wind turbines, and the impact of installing wind turbines on reducing carbon dioxide emissions were part of the study conducted in 2003 and 2004 in the UK (Dutton et al., 2005). The EU implemented a similar project in 2007 in three different countries: France, the Netherlands and, the UK. This study aimed at the results that come from the installation of wind turbines in urban areas, installing them in different areas of these states, and regulating the relevant legislation for the installation of wind turbines in residential areas (WINEUR, 2005). A general study on the installation of wind turbines in the built environment was done in France in 2004, where 60 wind turbines were installed in the built environment by the Regional Environment and New Energy Agency (ARENE) (Grignoux et al., 2004). Except the built environment, some studies were done in laboratories, like wind tunnels (Ramdlan et al., 2016). In 2011, Christine Beller from Danish Technical University focused her thesis on urban wind energy, comparing power production results from three different wind turbines installed at the Ørsted institute rooftop (Beller, 2011). The study focused on the design of the blades of the turbine and the obstacles around the place where turbines were installed.

A number of researches on the possibility of incorporating wind energy in residential areas have also been carried out. In the beginning, studies were done more in the light of energy potential, field tests, blade designs, and the likes (Cho et al., 2011). These turbines were designed more for commercial purposes. The geometry of the buildings also plays a crucial role in Urban Wind Energy (Darvish et al., 2020). The connection between urban wind technology, environment, technological innovation, and sustainability is also very important when dealing with urban setting (Yusuf et al., 2018). The first deep academic study about Urban Wind Technology was done in the Netherlands at Delft Technical University in 2006. This study was conducted by Mertens, whereas a part of the study, he developed a turbine that operates especially in urban areas. The developed turbine was called TURBY, and its design was focused on tilted air flowing conditions on the rooftops. The impact of the turbine position on the roof was also studied as a part of the investigation (Bussel et al., 2004).

Later research has been carried out mainly in the United Kingdom. In 2007 in Leicestershire at Loughborough University, a study was done indicating Building-Mounted Ducted Wind Turbine (Watson et al., 2007). The performance of vertical axis wind turbines with curvature blades and helical blades was studied in 2010 at the University of Glasgow (Scheurich et al., 2010). Later that year, the University of Cambridge published a study investigating Energy Capture Through Gust-Tracking (Bertényi et al., 2012). In 2013 a study on Sizing and Simulation of PV-Wind Hybrid Power System was done at Solar Energy Institute Building at Ege University 2012. The study was focused on determining the potential wind and solar potential for the location where the building is positioned (Engin, 2013). More recently, researches have been done to compare the efficiency of varying wind turbines in various places in the built environment. Such a study was done in Massachusetts at Clark University in Worcester in 2017, comparing Horizontal and Vertical Axis Wind Turbines (Winslow, 2017). The study shows that HAWT produced more energy overall, with VAWT being more efficient on several low and moderate wind velocity days. Both turbines' power coefficient was very similar, with HAWT's average power coefficient of only 0.01 higher than VAWT.

More recently, the improvement in controlling small wind turbines in transition regions was studied in a journal article in 2020 (Ruz et al., 2020). Later at the beginning of 2021, a study was conducted on small wind turbines with Injection Molded Blades. This research was proven numerically and experimentally (Kim et al., 2021).

Similar research to the Clark University (Winslow, 2017) is done in this paper to compare Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) performances in the urban area of Prishtina. Details and results are presented below.

2. Current environment and energy situation in Kosovo

In Kosovo, most of the electricity is produced by Kosova A and Kosova B coal-based power plants. Power plant's capacity has been dropping through the years, caused by a number of factors, mostly by system failures, connection problems, and repairs. The last war negatively impacted system failures and the efficiency of the power plants as well. Table 1 shows the main information for existing thermal power plants in Kosovo (Paci, F., 2018), (ERO, 2019). The maximum permissible emission limit of pollutants under the Directive 2008/50 EC on air quality and Maximum Allowed Values (MAV) (EU, 2008) according to AI No. 02/2011 on Air Quality Assessment (AQA) for large combustion plants is as follows (Entec, 2005):

- $SO_2 \leq 400$ mg/m^{3}N
- $NO_x \leq 500$ mg/m^{3}N
- Dust ≤ 50 mg/m^{3}N

Table 1 The main data about Kosovo's existing power thermal plants

Power Plant	Installed Capacity [MW]	Max available capacity [MW]	First-year of work	Last year of work
Kosova A1	65	-	1962	2007
Kosova A2	125	-	1965	2002
Kosova A3	200	130	1970	-
Kosova A4	200	130	1971	-
Kosova A5	210	135	1975	-
Kosova B1	339	240	1983	2030
Kosova B2	339	260	1984	2030

European Union Agency For The Cooperation Of Energy Regulators in the Opinion No 22/2019 states thatthe maximum allowed value of CO_2 pollution for fossil fuels power plants is 350 grams of CO_2 per kilowatt-hour (350 gCO_2/kWh or 350 kgCO_2/MWh) (ACER, 2019). Knowing that the annual capacity of Kosova A and Kosova B power plants is around 5250 GWh (Lajqi et al., 2020), the maximum allowed emission of CO_2 from these Power Plants is:

$$CO_{2(max)} = 350\ \text{kg/(MWh)}\cdot 5250\cdot 10^3\ 000\ \text{MWh} = 1837500000\ \text{kg}$$
$$CO_{2(max)} = 1837500\ \text{tons} = 1837.5\ \text{kilotons} \quad (1)$$

Emission from Kosova A and Kosova B power plants is presented in Figure 1, where cumulative yearly pollution is compared with the maximum allowed values of SO_2, NOx, and dust for the years 2010 to 2019 (ERO, 2016), (KEPA, 2019). Emission of CO_2 is presented only up to 2016 and are given for both power plants together, as the data given were on this form (MESP, 2014).

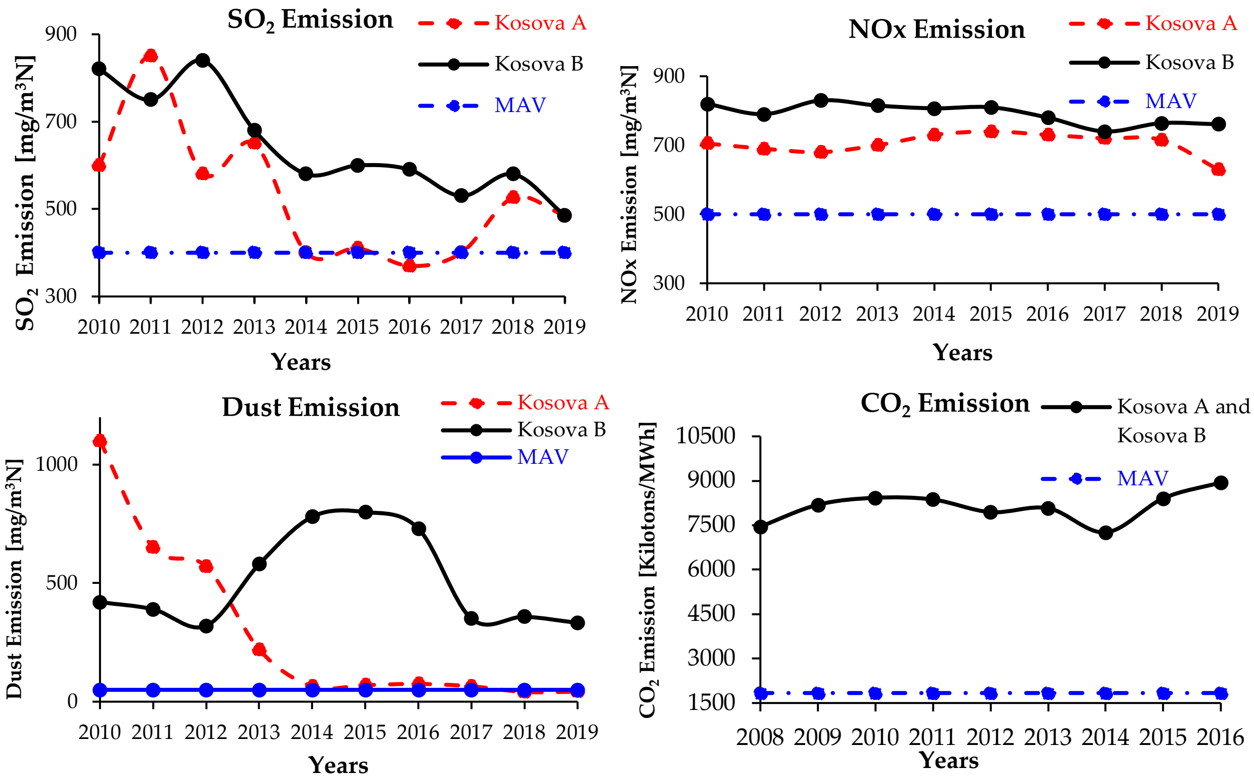

Figure 1 Emission of Gases from Kosova A and Kosova B Power Plants and comparison with MAV

From Figure 1, Kosova A and Kosova B plants exceed the limits of the emission of hazardous gases as well as dust multiple times. Kosova A and Kosova B have exceeded the emission of CO_2 by more than four times. Thus, actions to lowering this amount of emission must be taken to reduce the emission limits to a harmless level (HEAL, 2016).

2.1. Renewable energy situation

Energy Regulatory Office (ERO), the office that regulates activities in the energy sector in Kosovo, separates the renewable resources into three categories:

1. Power Plants that are in operation,
2. Power Plants that have the final authorization and can start operating whenever they are ready, and
3. Power Plants that have the preliminary authorization and are in the procedure of gaining the final authorization.

The total capacity of renewable power plants, from those working, those with authorization and preliminary authorization, is presented in Table 2 (ERO, 2020). To promote investment in the generation of electricity from renewable sources, feed-in-tariffs have been applied in the base of shared energy that is sent to the grid. Feed-in tariffs for renewable energy resources are applied only for the production of on electricity. The feed-in tariffs scheme for electricity production from specific renewable energy resources looks as shown in Table 3 (ERO, 2020).

Table 2 Total installed capacity of Renewable Power Plants

Resources	Power Plants in operation [MW]	Power Plants planned to be installed [MW]	TOTAL [MW]
Hydro Power plants	31.20	78.80	110.00
Photovoltaic Systems	6.60	90.69	97.29
Wind Farms	33.75	349.60	383.35
TOTAL	71.55	519.09	590.64

Table 3 Feed-in tariffs for Renewable Energy Sources in Kosovo

Renewable Energy Sources	Feed-in tariff [€/MWh]
Photovoltaic	136.40
Wind	85.00
Biomass	71.30
Small Hydro Power Plants	67.47

According to table two, some wind farms are already installed or are being installed in different areas of Kosovo. There is an amount of 349.6 MW that is planned to be produced by wind farms that are being built in different areas of Kosovo'. On the other hand, installing renewable energy sources inside the urban environment hasn't been applied yet in this country. As for now, and from what is known, this research is the first of this kind which analyzes the potential of power production from any renewable resources inside any urban environment. This research is focused on the potential of power production from wind turbines in one area of Prishtina city, the capital of Kosovo. The production of energy from inside the urban areas is very important since it eliminates the energy losses in transmission and helps cover city common expenses, like street lights, without using fossil fuels in an environmental-friendly way. Results of the research are presented in the end, reaching the three targets set at the beginning of the research.

3. Power Generation from Wind Turbines

Wind turbines convert the kinetic energy of the wind into rotational kinetic energy of the turbine, from where it can be converted into electricity using a generator.
The following expression can estimate the power of energy given by a wind turbine:

$$P = \frac{\rho \cdot A \cdot v^3}{2}, \quad [W] \tag{2}$$

where are:

ρ [kg/m^3] - Air density
A [m^2] - Swept area of the turbine
v [m/s] – Wind velocity

Equation (2) represents the theoretical power generation from a wind turbine (Liu, 2019; Zhang et al., 2019; Manyonge et al., 2012).

3.1. Power Coefficient (Betz Limit)

Albert Betz, a German scientist, discovered the law that holds his name in 1919, the so-called Betz Limit or Betz Law. As given by Albert Betz, the theoretical maximum efficiency of wind turbines is 59.3%. To understand better the Betz Limiit is necessary to go through the mathematical form of the Betz limit, which is explained through the upstream and downstream wind velocities, as shown in Figure 2 (OpenMDAO, 2021).

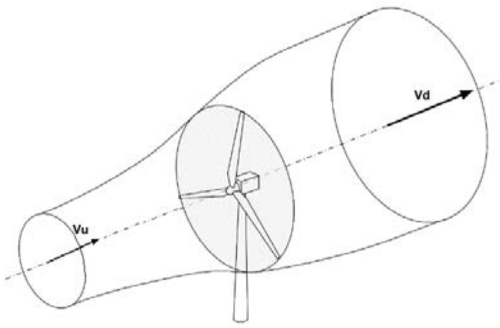

Figure 2 Schematic presentations for calculation power of wind turbine

The mechanical energy converted by rotor blades of wind turbines is dependent in the difference between upstream and downstream wind velocities (Manyonge et al., 2012). Adding these velocities to the equation (1) results to:

$$P_\omega = \frac{1}{2}\rho \cdot A \cdot v_\omega \left(v_u^2 - v_d^2\right), \quad [W] \tag{3}$$

where are:

V_u [m/s] - upstream wind velocity at the entrance of the rotor blades
v_d [m/s] - downstream wind velocity at the exit of the rotor blades
v_ω [m/s] - an average of two velocities in the entrance and the end of blades

The mass flow rate will be as follows:

$$\rho \cdot A \cdot v = \frac{\rho \cdot A \cdot \left(v_u + v_d\right)}{2}, \quad \left[\frac{kg}{s}\right] \tag{4}$$

Adding this to equation (3) will result as follows:

$$P_\omega = \frac{1}{2}\rho \cdot A \cdot \left(v_u^2 - v_d^2\right)\frac{\left(v_u - v_d\right)}{2}, \quad [W] \tag{5}$$

Equation (5) can be expanded in the following form:

$$P_{\omega}=\frac{1}{2}\left[\rho\cdot A\cdot\left(\frac{v_u}{2}\left(v_u^2-v_d^2\right)+\frac{v_d}{2}\left(v_u^2-v_d^2\right)\right)\right]=$$
$$=\frac{1}{2}\left[\rho\cdot A\cdot\left(\frac{v_u^3}{2}-\frac{v_u\cdot v_d^2}{2}+\frac{v_u^2\cdot v_d}{2}-\frac{v_d^3}{2}\right)\right]= \tag{6}$$
$$=\frac{1}{2}\left[\rho\cdot A\cdot v_u^3\left(\frac{1-\left(\frac{v_d}{v_u}\right)^2+\left(\frac{v_d}{v_u}\right)-\left(\frac{v_d}{v_u}\right)^3}{2}\right)\right],\quad [W]$$

The right part of equation (6) is actually the Betz limit mathematical form:

$$C_p=\frac{1-\left(\frac{v_d}{v_u}\right)^2+\left(\frac{v_d}{v_u}\right)-\left(\frac{v_d}{v_u}\right)^3}{2} \tag{7}$$

From equations (6) and (7), the energy produced from wind turbines is:

$$P=\left(\frac{\rho\cdot A\cdot v^3}{2}\right)\cdot C_p,\quad [W] \tag{8}$$

If we replace the ratio of downstream and upstream wind velocities with a symbol τ:

$$\tau=\frac{v_d}{v_u} \tag{9}$$

then Betz limit mathematical form will be:

$$C_p=\frac{1-\tau^2+\tau-\tau^3}{2}\ or\ C_p=\frac{(1+\tau)\left(1-\tau^2\right)}{2} \tag{10}$$

The power coefficient or the Betz limit varies from the winding ratio of the turbine. Giving different values to τ will give us different values of C_p. The C_p will have the maximum value when the difference of it with respect to τ is equal to zero:

$$\frac{dC_p}{d\tau}=\frac{(1+\tau)(-2\tau)+\left(1-\tau^2\right)}{2}=0 \tag{11}$$

From here, the values τ are $\tau_1=-1$ and $\tau_2=1/3$, where τ_2 makes the C_p value maximum. Adding the value of τ_2 in equation (11) will give us the result for C_p, which will be 0.593, which is actually the maximum value of the Betz limit. "The Betz limit says in particular: No wind turbines can convert more than (59.3%) of the wind kinetic energy into mechanical energy turning a rotor, or Cp_{max} = 0.593".

4. Urban Wind Technology

Studies and research have been done in recent years on installing wind turbines inside urban areas (Beller, 2011). Being quite a new technology, Urban Wind Turbines have a very high cost even though their efficiency remains quite low. The huge advantage of installing Wind Turbines in Urban areas is the direct use of energy for the building's needs, eliminating the energy transmission losses. This technology needs yet to be explored, such as its impact on urban areas, vibrations, their best position, noise, and the like remaining to be studied (Krasniqi, 2021).

4.1. Case Study – Prishtina

To determine the potential of energy production from the wind, firstly, a spot inside the city of Prishtina has been chosen to install the devices. The chosen place is the Laboratory building of the Technical Faculties of the University of Prishtina "HASAN PRISHTINA" Prishtina, Kosovo. Devices have been installed on the rooftop of this building, at the height of 11 meters above the ground, respectively, 615 meters above sea level. All the necessary equipment for this study has s been installed in Prishtina City.

Figure 3 shows the location within Prishtina city taken from Global Wind Atlas (2021), with 3D picture taken from Google Maps. The devices that were installed in this place for this research include a HAWT, a VAWT, and a Meteorological Weather Station (MWS), shown in Figure 4. Devices will provide power production from each wind turbine and meteorological data from the weather station. Finally, it will be possible to state which of these turbines is more suitable to be installed in this area of the city of Prishtina and how much electricity they produce.

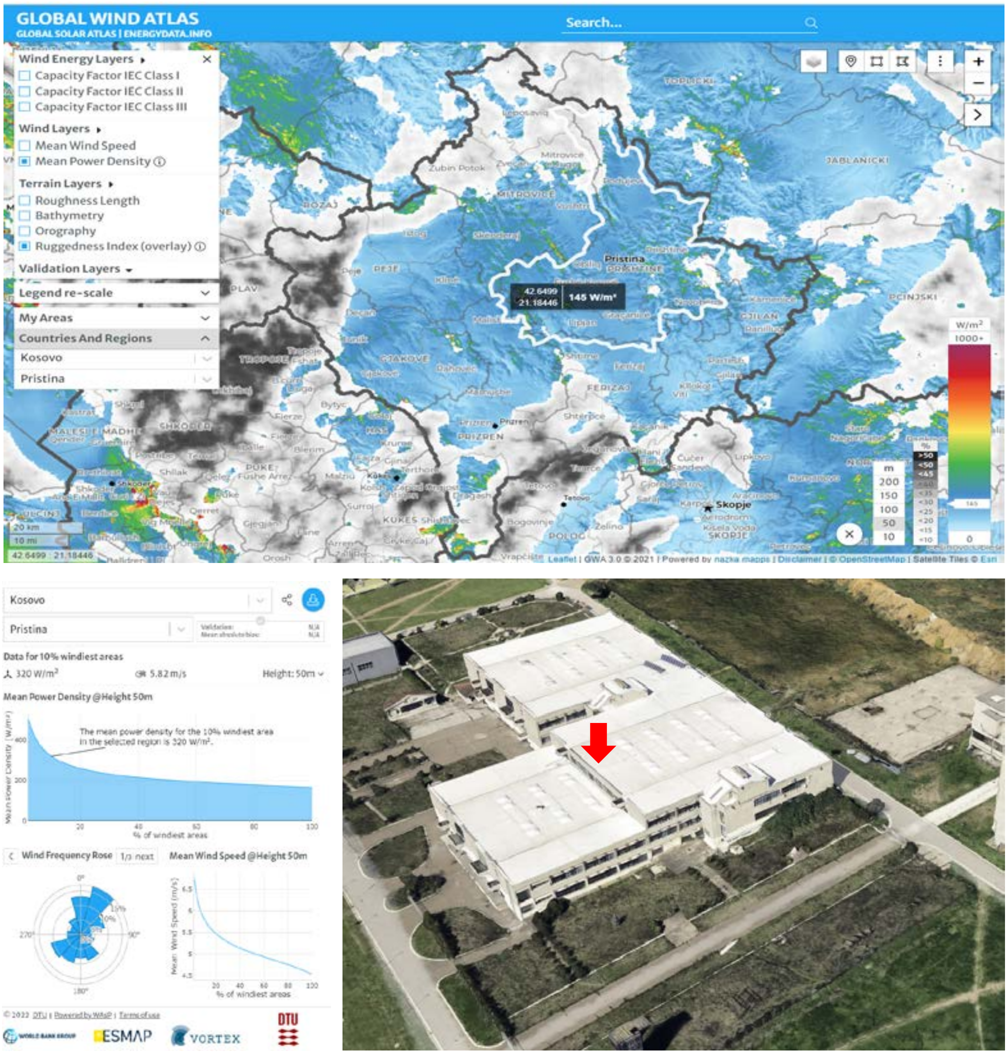

Figure 3 Location where experimental devices are installed (Laboratories of Technical Faculties of University of Prishtina "HASAN PRISHTINA" (Wind atlases for Kosovo)

Figure 4 HAWT (left), VAWT (middle), and MWS (right) installed in the rooftop of the Laboratory building of the Technical Faculties of the University of Prishtina "HASAN PRISHTINA"

Wind turbines and MWS are connected with corresponding inside devices in one of the Technical Faculties Laboratory classrooms. Wind turbines are connected with: two 12 volts of DC batteries, controllers, and offline modules to register the power production. A 2000 watts pure sine power inverter is used to convert 12 volts DC electricity into 220-240 volts AC, and it is combined with devices shown in Figure 5.

Figure 5 Used devices for research: a) Hybrid controller, b) Offline storage module, c) DC/AC Inverter, d) Batteries, e) Metrological device, and f) Automatic switch

Hybrid controllers to show how the online energy production data is on a small monitor that is part of the controller. Besides that, hybrid controllers also have overcharge protection from the system.

Offline storage modules serve to store system history data in SD cards. The offline storage module collects the electricity data from the controller per second and saves them into an SD card per minute.

The power inverter serves to convert the 12 VDC electricity into 220 VAC electricity.

Batteries accumulate electricity produced from wind turbines.

The meteorological device inside the unit – serves to show and share the weather data from the outside unit, and

The automatic switch serves to switch the connection from the grid to the batteries when the batteries are loaded and switch the connection from the batteries to the grid when the batteries are under necessary voltage.

All the devices were installed during the year 2018, as the data presented in this research is for the years 2019 - 2020. To better understand the connections between outside and inside units of the devices installed for this research, a schematic view of these devices is presented in the scheme shown in Figure 6.

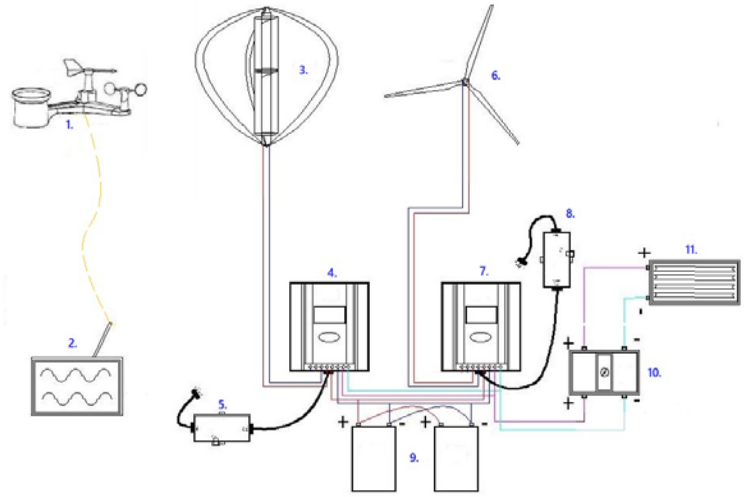

Figure 6 Installation scheme: 1. The outside unit of MS, 2. Inside unit of MS, 3. VAWT, 4. VAWT-s controller, 5. VAWT-s offline storage module, 6. HAWT, 7. HAWT-s controller, 8. HAWT-s offline storage module, 9. 12 Volts batteries, 10. Automatic Switch and 11. DC/AC power inverter

5. Discussion

The wind data results can be presented in different forms. One of the most preferred methods to present the wind data is by drawing wind roses. Wind roses show how wind direction, distribution, and frequency change. They can be used to show both the wind velocity and direction. A software called Pavanaarekh, a free tool for research purposes is used to draw the wind rose. The wind-rose for installed HAWT and VHAT devices on the rooftop of the Laboratory building of the Technical Faculties for 2020 is shown in Figure 7.

From the wind-rose presented in Figure 7, the average wind velocity of 2020 is 1.63 m/s. The highest registered average wind velocities were in March and April, registering an average of 1.88 and 1.91 m/s. The lowest wind velocity registered in August and September 2020, when average velocities were below 1.5 m/s.

Wind direction most of the time is north and north-north-west. This direction is also verified by other research done before for Prishtina wind roses, verifying that wind in Prishtina blows mostly from these directions.

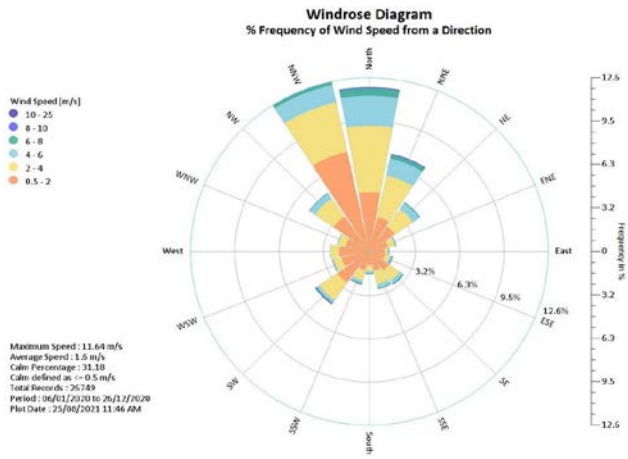

Figure 7 Wind-rose draw for 2020 for the position where research devices are installed

5.1. Wind turbines power production

The average wind velocity, amount of power produced each month, and the total amount of power produced annually from HAWT and VAWT in Laboratory building of the Technical Faculties of the University of Prishtina "HASAN PRISHTINA", Prishtina, Kosovo during the years 2019 - 2020 are presented in Table 4 (Krasniqi, 2021).

From Table 4, it can clearly be seen that HAWT is way more efficient than VAWT for the position and place where they are installed. HAWT produces more electricity than VAWT about 3 - 4 times, which answers the question of which turbine is more suitable to be installed in this area. This can also be presented with power production curves in the report to the average wind velocities. It can also be seen that the wind velocity in this area is not very high. One of the reasons is the obstacles that are placed around the location. Considering these results, the installation of small wind turbines in this urban area needs deeper studies on the location, the model of the turbines that are going to be installed, and the purpose of installation.

Table 4 Total installed capacity of Renewable Power Plants

MONTHS	Average Wind Velocity [m/s]		HAWT Electricity produced [kWh]		VAWT Electricity produced [kWh]	
	2019	2020	2019	2020	2019	2020
January	0.94	1.52	10.25	16.58	3.33	4.31
February	1.80	1.80	19.63	19.63	6.38	5.11
March	1.55	1.91	16.91	20.83	5.50	5.42
April	1.88	1.88	20.50	20.50	6.67	5.33
May	1.66	1.86	18.11	20.29	5.87	5.28
June	1.36	1.43	14.83	15.60	4.82	4.06
July	1.44	1.50	15.71	16.36	5.11	4.26
August	1.14	1.45	12.43	15.81	4.04	4.11
September	1.31	1.41	14.29	15.38	4.65	3.99
October	0.95	1.55	10.36	16.91	3.37	4.40
November	1.75	1.75	19.09	19.07	6.21	4.96
December	1.55	1.55	16.91	16.91	5.50	4.40
Total	*Average* *1.44*	*1.63*	*189.01*	*213.87*	*61.45*	*55.63*

Figure 8 shows the comparison of the total power produced daily by each wind turbine in function to average daily wind velocity.

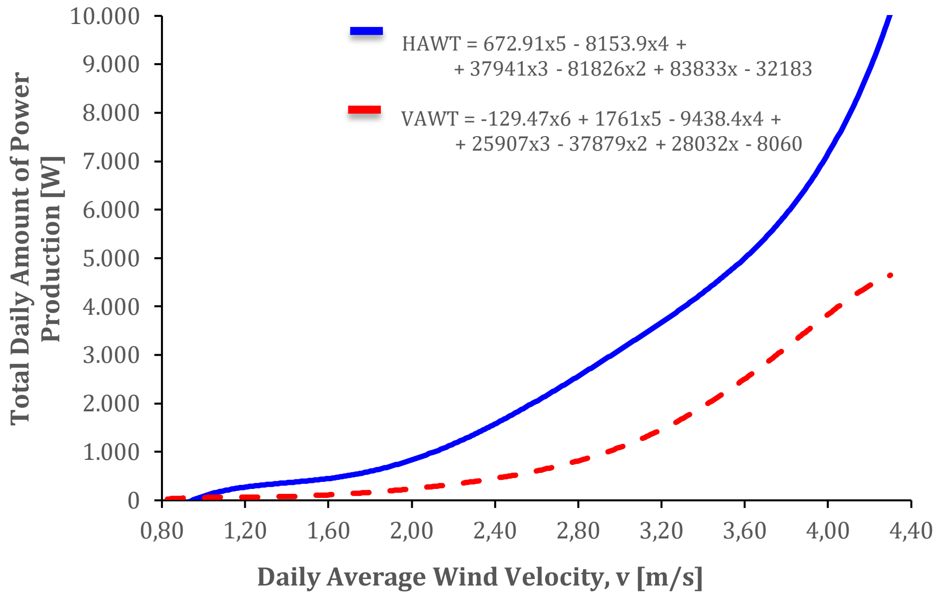

Figure 8 Comparison of HAWT and VAWT curves for the daily amount of power produced

HAWT is more efficient than VAWT because HAWT has better performance at the wind velocities for the location and conditions where these turbines are installed. This is presented graphically also later in Figure 8.

Even with the obstacles and problems shown, HAWT with 300 W capacity has given quite good results. It has produced 214 kWh of electricity for the year 2020. The combination of this power with solar energy will for sure give better results. Studies on the combination of wind and solar energy in this area remain to be studied for future investigation. Considering that the wind turbine which is chosen for our case study in Urban Areas is quite small and has a capacity of only 300 W, a bigger turbine might be able to cover a higher amount of energy to cover the power required for consumption.

5.2. Power curves of Horizontal Wind Turbine

HAWT has given better results than VAWT. This way, only the HAWT will be used for further studies. HAWT is a small wind turbine that has an installed capacity of 300 W. This HAWT is called S-300W Wind Turbine Generator; it has three blades made of nylon composite materials and has an electric tension potential of 12 volts. The most common method to express the characteristics of a wind turbine is by presenting the power curve. The power curve represents the power produced by a wind turbine (Watts) in different moment wind velocities. The results from the power produced by wind turbines during the year 2020 are used to draw the power curve. This power curve is presented in Figure 9.

Figure 9 shows the real power curve, which is drawn using the power produced by the wind turbine in the year 2020, and the theoretical power curve that the producer gives. This way, it is possible to see the difference between the real and theoretical power curves.

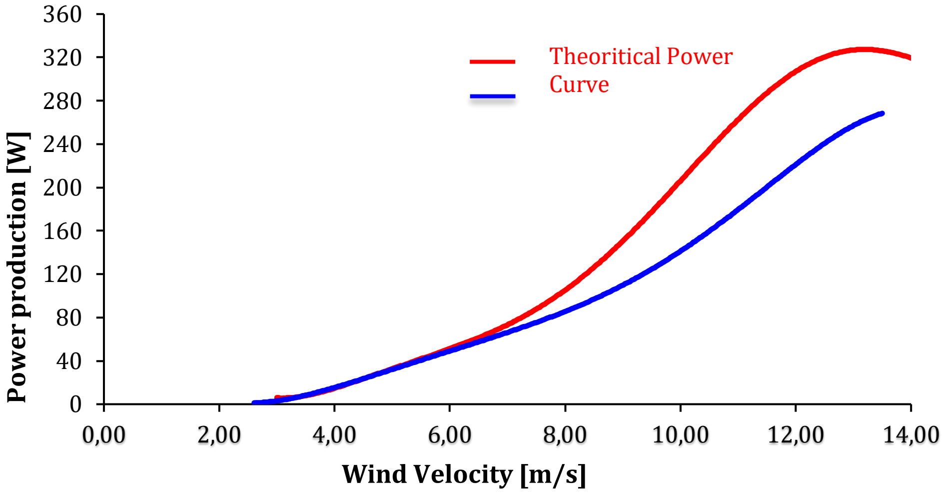

Figure 9 Theoretical and real power curves of the HAWT

HAWT starts producing electricity at a wind velocity of around 1.5 m/s. The power production increases with the increase of wind velocity. The highest registered power production by the HAWT is registered in March 2020. The amount of energy produced was 263.9 W at the wind velocity of 13.5 m/s.

5.3. Power coefficient of Horizontal Wind Turbine

To calculate the power coefficient of any HAWT, it is needed to go through the mathematical model of the wind turbines' power production. Chapter two of this paper deals especially with this issue, which is the power that can be generated from wind turbines. From the equation (8), the power coefficient expression can be extracted and written as follows:

$$C_p = \frac{2 \cdot P}{\rho \cdot A \cdot v^3} \tag{12}$$

The graphic form of the power coefficient for HAWT for study cases is presented in Figure 10. It shows the real Betz coefficient percentage in different wind velocities. For our study research case, the power coefficient reaches a maximum of C_{pmax} = 34.3% at a wind velocity of 4.5 m/s. In the beginning, this coefficient has a rapid increase with the increase of small wind speeds, where the turbine starts working at speeds around 1.5 m/s. After reaching the maximum point, the power factor experiences a much slower drop at higher wind velocities.

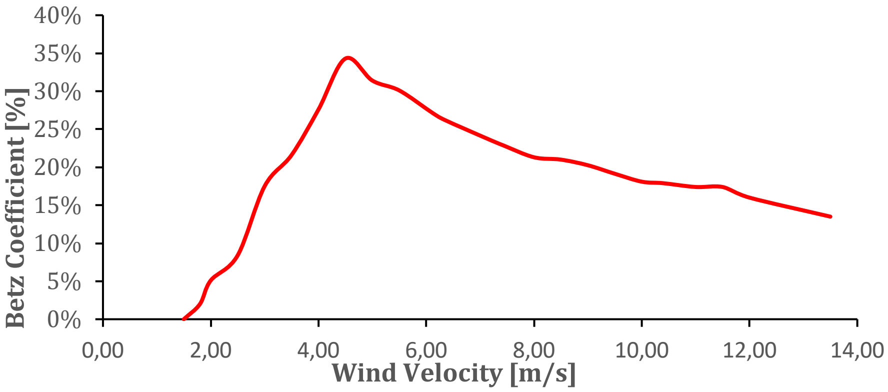

Figure 10 Power Coefficient of HAWT (Betz limit)

6. Conclusions

This paper investigates wind potential for one part of the urban area of Prishtina by showing the power production of two installed wind turbines: Horizontal and Vertical Axis wind turbines. Both turbines were performing for two years, throughout 2019 and 2020. Results show that installing wind turbines in this area is recommended in certain conditions. The spot which is chosen for this research has many obstacles around it. So, the wind velocity in this spot is hampered by the objects around the spot. Installation of wind turbines in this area requires studies if obstacles hamper the wind in the height where wind turbines will be placed. HAWT produced 189.01 kWh on 2019 and 213.87 kWh on 2020, thus giving better results than VAWT, which produced 61.5 kWh on 2019, and 55.63 kWh on 2020. Part of the study was also the comparison of theoretical and real wind turbines data. The real and theoretical data of the wind turbine are close to each other, with real data being slightly lower than theoretical, a result that was expected. Afterward, the characteristics of the turbine, in this case, the HAWT, are presented graphically, where the power curve and power coefficient are presented. The higher power coefficient registered is 34.3% at the wind velocity of 4.5 m/s, while the highest registered power produced is registered in March, where 263.9 W were produced at the wind velocity of 13.5 m/s. The combination of wind and solar energy in electricity production for this area remains to be studied in the future.

References

Agency For Cooperation Of Energy Regulators (ACER), 2019. Opinion No 22/2019 of The European Union Agency. European Union Agency For Cooperation Of Energy Regulators

Beller, C., 2011. *Urban Wind Energy.* Doctor's Thesis, Technical University of Denmark-DTU, Denmark

Bertényi, T., Wickins, C., McIntosh, S., 2012. Enhanced Energy Capture Through Gust-Tracking in the Urban Wind Environment. *In*: 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition

Bussel, G. V., Mertens, S., Polinder, H., Sidler, H.F.A., 2004. TURBY, Concept and Realisation of a Small VAWT for the Built Environment. *In*: The Science of Making Torque from Wind.

Campbell, N., Stankovic, S., Graham, M., Parkin, P., Duijvendijk, M.V., Gruiter, T.D., Behling, S, Hieber J., Blanch, M., 2001. Wind Energy for the Built Environment (Project Web). *In*: European Wind Energy Conference & Exhibition, Copenhagen

Cho, K.P., Jeong, S.H., Sari, D.P., 2011. Harvesting Wind Energy from Aerodynamic Design for Building Integrated Wind Turbines. *International Journal of Technology*, Volume 2(3), pp. 189–198

Darvish, A., Eghbali, S.R., Eghbali, G., Mahlabani, Y.G, 2020. The Effects of Building Glass Façade Geometry on Wind Infiltration and Heating and Cooling Energy Consumption. *International Journal of Technolog,* Volume 11(2), pp. 236–247

Dutton, G.A., Halliday, J., Blanch, M.J., 2005. *The Feasibility of Building-Mounted/Integrated Wind Turbines (BUWTs): Achieving their Potential for Carbon Emission Reductions*. Final Report, Energy Research Unit, CCLRC

Energy Regulatory Office (ERO), 2016. Monitoring Report for KEK. Report, Energy Regulatory Office, Republic of Kosovo, Prishtina

Energy Regulatory Office (ERO), 2019. *Electricity and Thermal Energy Balance 2020.* Report, Energy Regulatory Office, Republic of Kosovo, Prishtina

Energy Regulatory Office (ERO), 2020. Annual Report 2019. Report, Energy Regulatory Office, Republic of Kosovo, Prishtina

Engin, M., 2013. Sizing and Simulation of PV-Wind Hybrid Power System. *International Journal of Photoenergy,* Volume 2013, pp. 1-10

Entec UK Limited (Entec), 2005. Preparation of the Review Relating to the Large Combustion Plant Directive. Final Report, European Commission, Environment Directorate General

Global Wind Atlas, 2021. *Wind Atlases for Kosovo.* Available online at https://globalwindatlas.info/area/Kosovo, Accessed on November 10, 2021

Grignoux, T., Gibert, R., Neau, P., Buthion C., 2004. Éoliennes en milieu urbain - État de l'art *(Wind Turbines in an Urban Environment - State of the art)*. Report, ARENE Ile-de-France.

Health and Environment Alliance (HEAL), 2016. The Unpaid Health Bill: How Coal Power Plants in KOSOVO Make us Sick. Kosovo: Health and Environment Alliance (HEAL)

Kim, B., Park, S.J., Ahn, S., Kim, M.G, Yang, H.G, Ji, H.S., 2021. Numerically and Experimentally Verified Design of a Small Wind Turbine with Injection Molded Blade. *Processes,* Volume 9(5), pp. 1–17

Kosovo Energy Corporation (KEC), 2021. Termocentrali "Kosova B". Available online at http://kek-energy.com/kek/termocentrali-kosova-b/

Kosovo Environmental Protection Agency (KEPA), 2019. Annual Report on the State of Air 2019. Report, Ministry of Infrastructure and Environment (MIE)

Krasniqi, G., 2021. *Application of Wind Energy in Urban Areas - Modelling of Urban Wind Turbines.* PhD Thesis, University St. Kliment Ohridski, Bitola, North Macedonia

Lajqi, S., Đurin, B., Berisha, X., Plantak, L., 2020. Analysis of the Potential for Renewable Utilization in Kosovo Power Sector. *Environments,* Volume 7(6). https://www.mdpi.com/2076-3298/7/6/49

Liu, Z., Tao, Y., Wei, L, Zhan, P., Yue, D., 2019. Analysis of Dynamic Characteristics of a 600 kW Storage Type Wind Turbine with Hybrid Hydraulic Transmission. *Processes,* Volume 7(7), p. 397

Manyonge, A.W., Manyala, R., Onyango, F.N., Shichika, J., 2012. Mathematical Modelling of Wind Turbine in a Wind Energy Conversion System: Power Coefficient Analysis". *Applied Mathematical Scinces,* Volume 6(91), pp. 4527–4536

Ministry of Environment and Spatial Planning (MESP), 2014. Climate Change Strategy (CCS) 2014-2024. Kosovo: Ministry of Environment and Spatial Planning

OpenMDAO Develpoment Team (OpenMDAO), 2021. Wind Turbine Actuator Disc: Optimizing an Actuator Disc Model to Find Betz Limit for Wind Turbines. Available online at https://openmdao.org/newdocs/versions/latest/examples/betz_limit.html

Paci, F., 2018. Mirëmbajtja E Pajisjeve Transportues te Thëngjillit *(Maintenance of Coal Transport Equipment).* Prishtinë: University of Business and Technology in Kosovo

Ramdlan., G.G., Siswantara, A.I., Budiarso, Daryus, A., Pujowidodo, H., 2016. Turbulence Model and Validation of Air Flow in Wind Tunnel. *International Journal of Technology*, Volume 7(8), pp. 1362–1372

Rizvanolli, D., 2019. *Kosovo's Potential for Renewable Energy Production: An Analysis.* Twente: University of Twente.

Ruz, M.L., Garrido J., Fragoso, S., Vazquez, F., 2020. Improvement of Small Wind Turbine Control in the Transition Region. *Processes,* Volume 8(2), p. 244

Scheurich, F., Fletcher, T.M., Brown, R.E., 2010. The Influence of Blade Curvature and Helical Blade Twist on the Performance of a Vertical-Axis Wind Turbine. *In*: 29th ASME Wind Energy Symposium, 4-7 January 2010, Orlando, Florida. h

Spanca, N., 2020. Gjendja Aktuale E Sistemi Sistemit Energjetik Dhe Potenciali I Energjisë Së Ripërtëritshme Në Kosovë *(Current Situation of the Energy System and the Potential of Renewable Energy in Kosovo).* Thesis, University Business and Technology in Kosovo, Republic of Kosovo

Stankovic, S., Campbell, N., Harries, A., 2009. *Urban Wind Energy.* London: Routledge

The European Parliament and the Council of the European Union (EU), 2008. *Directive 2008/50/Ec Of The European Parliament And Of The Council of 21 May 2008 On Ambient Air Quality and Cleaner Air for Europe.* Official Journal of the European Union.

Tong, Z., Haiyi, Z., 2016. A Text Mining Research Based on LDA Topic Modelling. *In*: The Sixth International Conference on Computer Science, Engineering and Information Technology, Vienna

Watson, S., Infield, D., Barton, J., Wylie, S.J., 2007. Modelling of the Performance of a Building-Mounted Ducted Wind Turbine. Journal of Physics Conference Series, Volume 75(1)

Wind Energy Integration in the Urban Environment (WINEUR), 2005. WINEUR Wind energy integration in the urban environment Deliverable 1.1. Technology Inventory Report

Winslow, A.R., 2017. *Urban Wind Generation: Comparing Horizontal and Vertical Axis Wind Turbines at Clark University in Worcester, Massachusetts*. Master's Papers, Clark University, Massachusetts, USA

Yusuf, M.F., Ashari, H., Razalli, M.R., 2018. Environmental Technological Innovation and Its Contribution to Sustainable Development. *International Journal of Technology*. Volume 9(8), pp. 1569–1578

Zhang, Y., Zhang, L., Liu, Y., 2019. Implementation of Maximum Power Point Tracking Based on Variable Speed Forecasting for Wind Energy Systems. *Processes,* Volume 7(3), p. 158